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(54) **TIME TO TIME-FREQUENCY MAPPING AND DEMAPPING FOR ETHERNET PASSIVE OPTICAL NETWORK OVER COAX (EPOC)**

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(51) **Int. Cl.**

***H04Q 11/00*** (2006.01)
***H04L 5/00*** (2006.01)

(52) **U.S. Cl.**

CPC ............ ***H04Q 11/0067*** (2013.01); *H04L 5/001* (2013.01); *H04L 5/0007* (2013.01); *H04Q 2213/1301* (2013.01); *H04Q 2213/13389* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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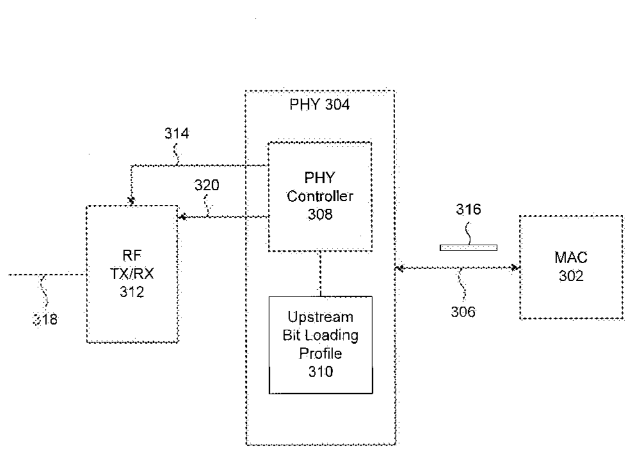
(57) **ABSTRACT**

Embodiments include, but are not limited to, systems and methods for enabling Orthogonal Frequency Division Multiple Access (OFDMA) in the upstream in an Ethernet Passive Optical Network over Coax (EPoC) network. Embodiments include systems and methods for translating Ethernet Passive Optical Network (EPON) upstream time grants to OFDMA resources represented by individual subcarriers of an upstream OFDMA frame. In an embodiment, the translation of EPON upstream time grants to OFDMA resources ensures that Coaxial Network Units (CNUs) sharing an OFDMA frame do not use overlapping subcarriers within the frame. Embodiments further include systems and methods for timing upstream transmissions by the CNUs in order for the transmissions to be received within the same upstream OFDMA frame at a Fiber Coax Unit (FCU). Embodiments further include systems and methods for re-generating a data burst from OFDMA resources for transmission from the FCU to an Optical Line Terminal (OLT).

**20 Claims, 14 Drawing Sheets**



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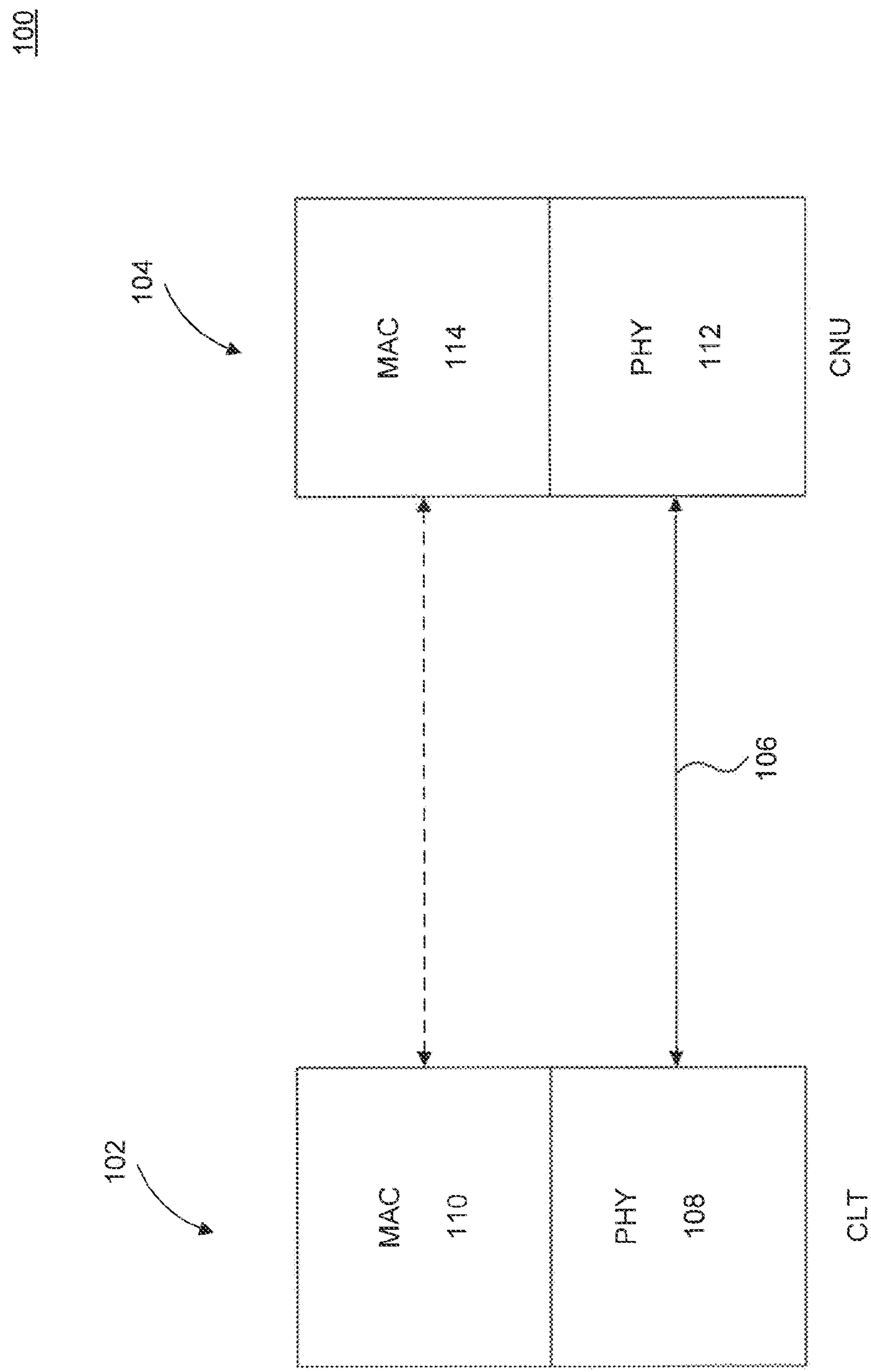


FIG. 1

200

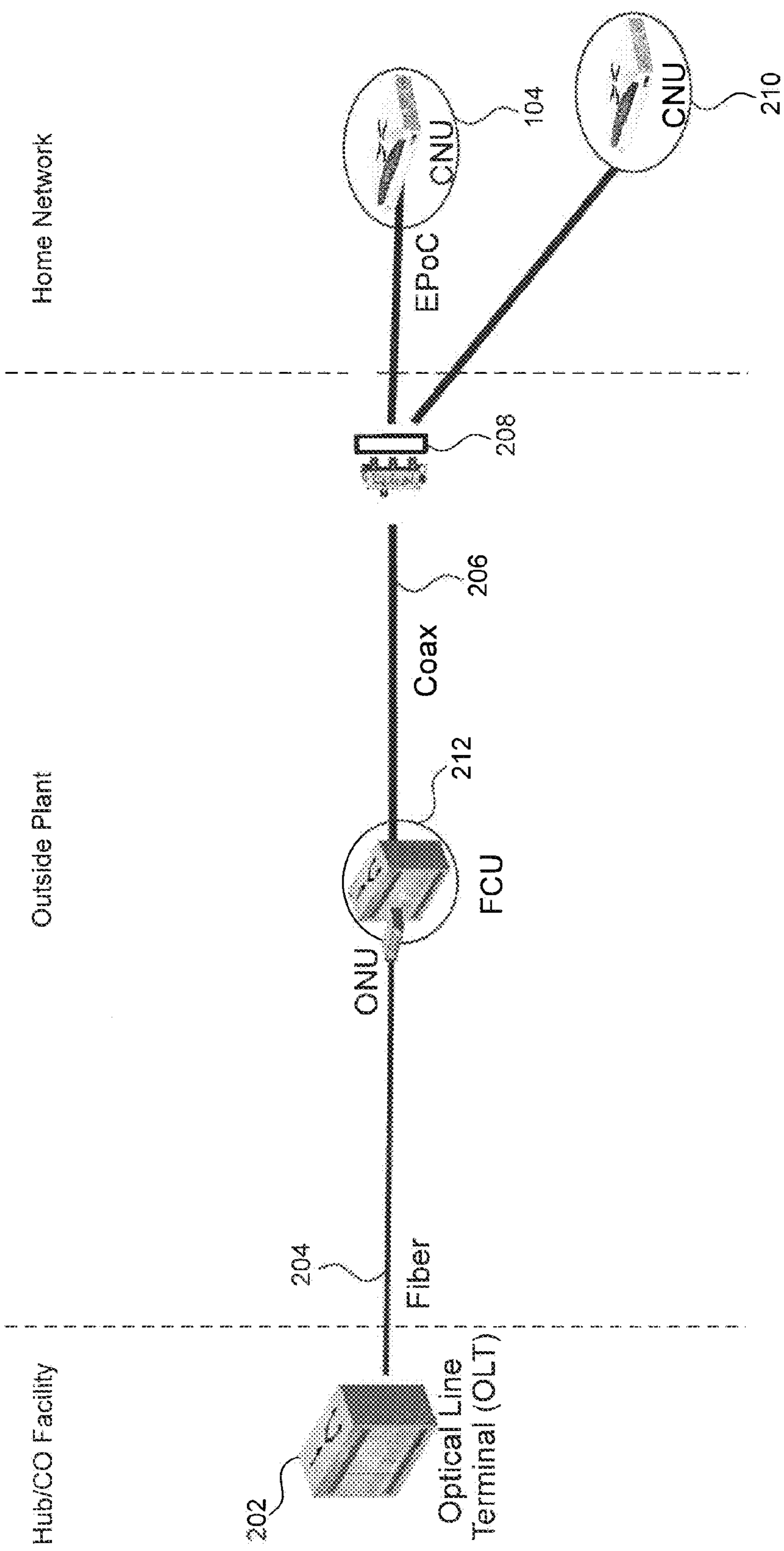
Hub/CO Facility
Outside Plant
Home Network
202
Optical Line Terminal (OLT)
204
Fiber
ONU
FCU
212
Coax
206
208
EPoC
CNU
104
CNU
210

FIG. 2

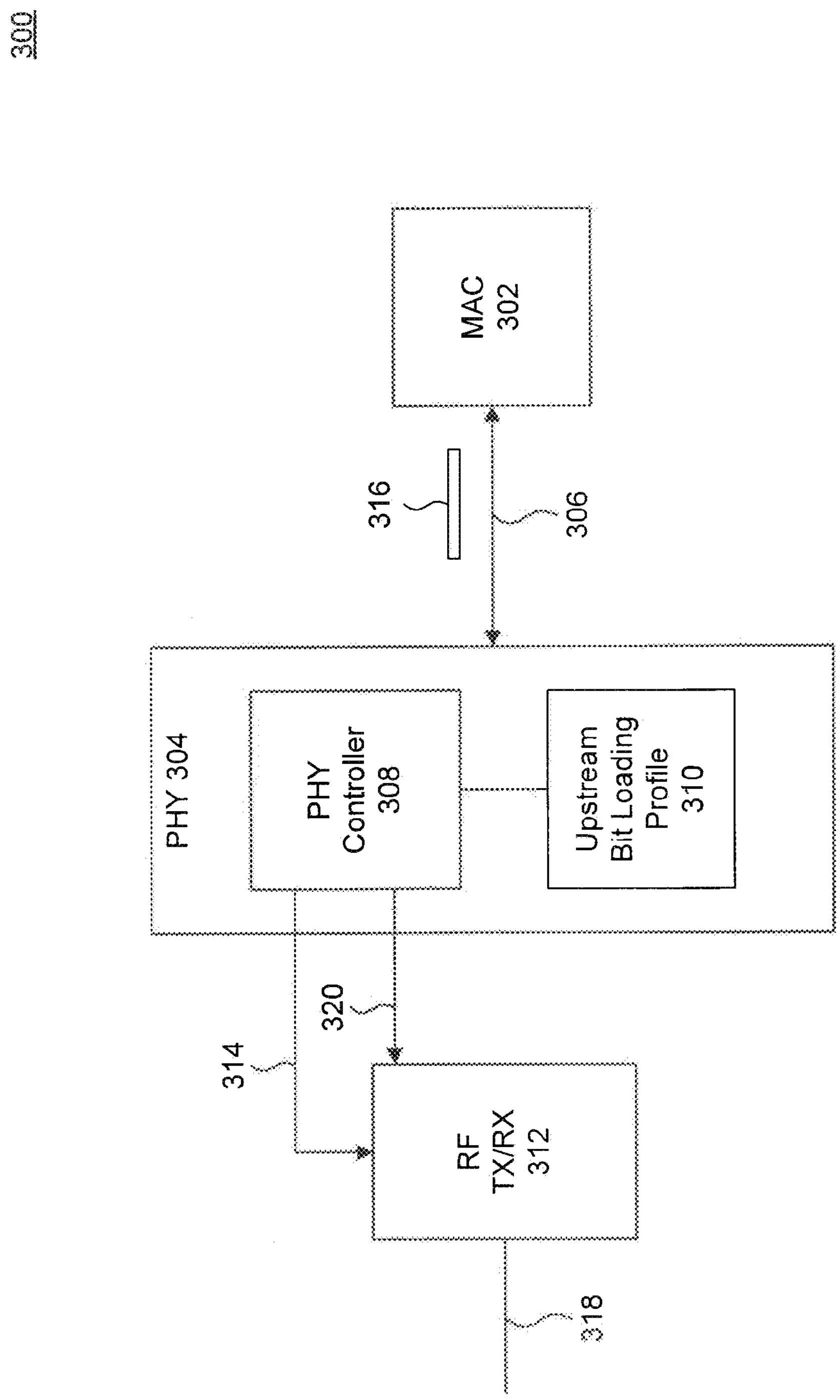
300
MAC 302
316
306
PHY 304
PHY Controller 308
Upstream Bit Loading Profile 310
320
314
RF TX/RX 312
318

FIG. 3

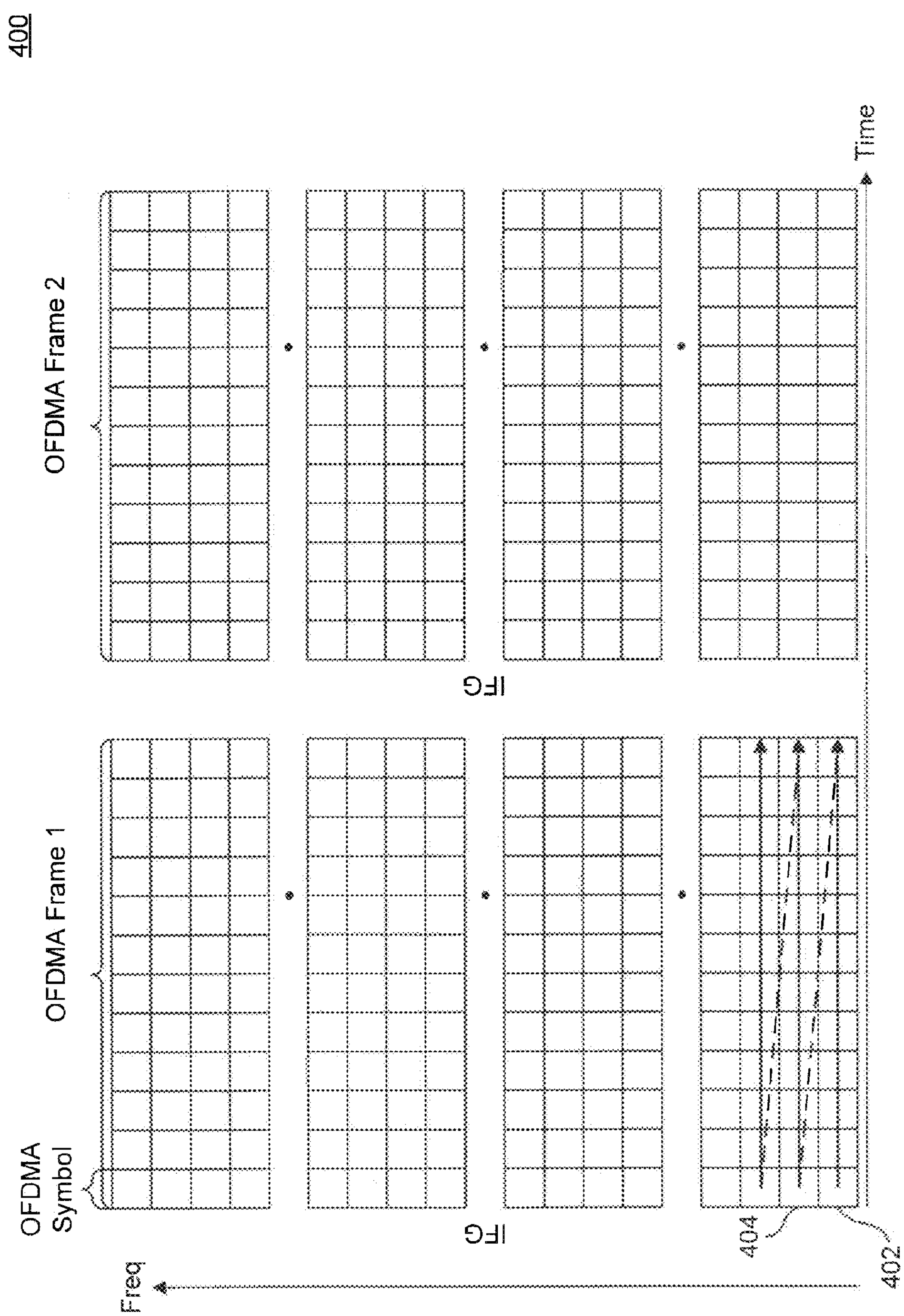
400
OFDMA Frame 1
OFDMA Frame 2
OFDMA Symbol
IFG
IFG
Time
Freq
404
402

FIG. 4

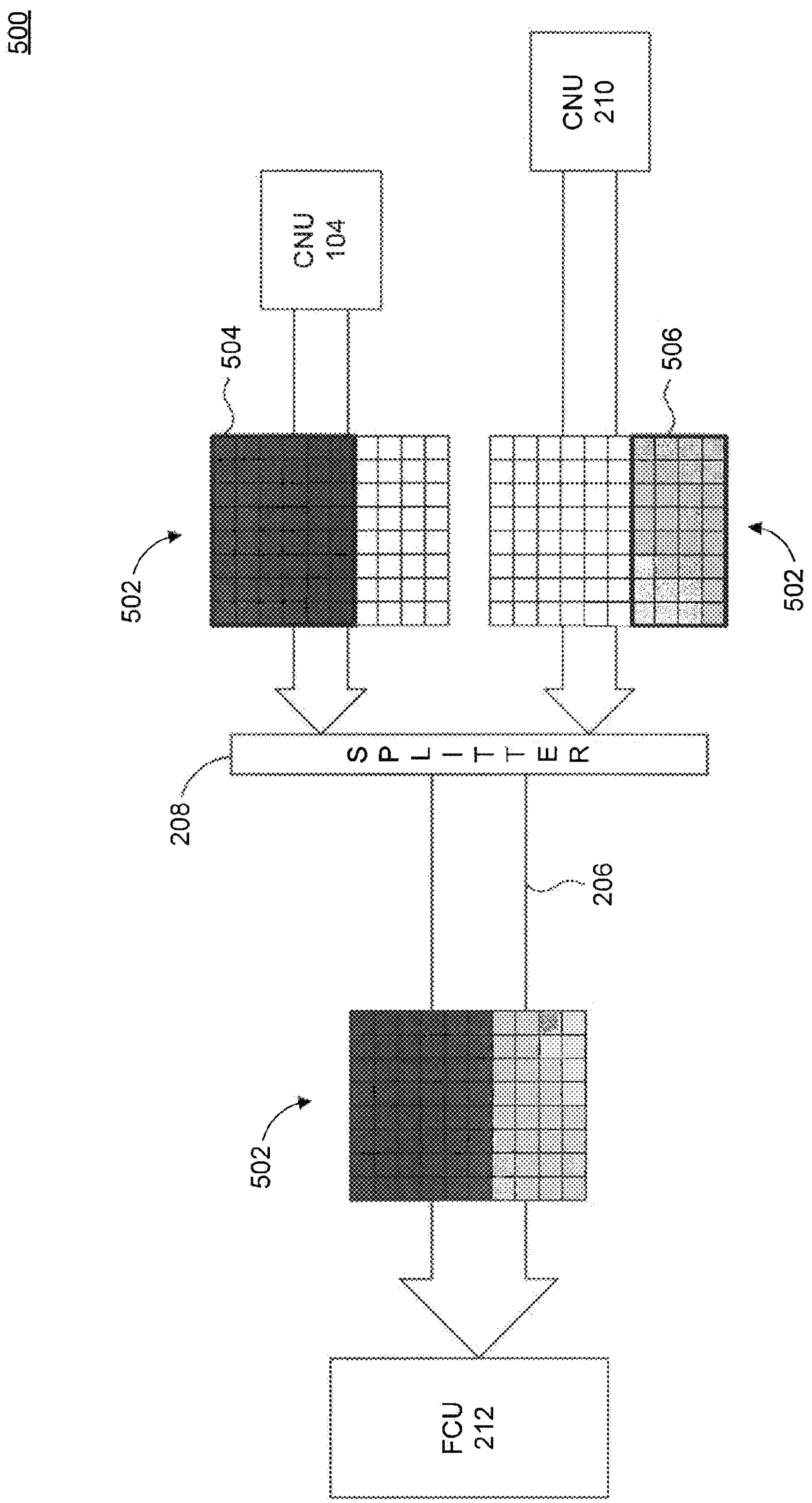
500
CNU 104
CNU 210
504
506
502
502
502
SPLITTER
208
206
FCU 212

FIG. 5

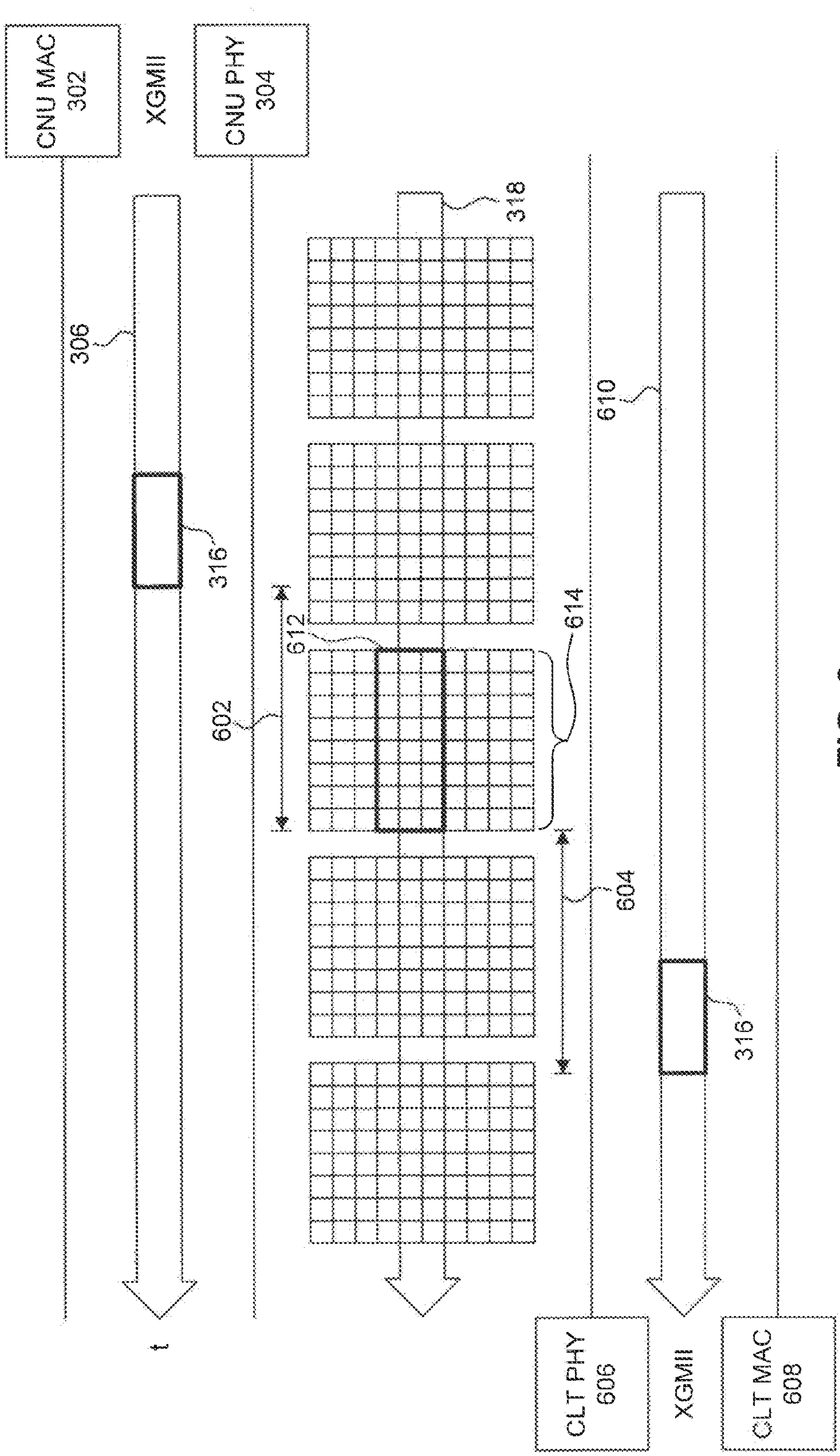
CNU MAC
302
XGMII
CNU PHY
304
306
316
318
602
612
614
604
610
316
t
CLT PHY
606
XGMII
CLT MAC
608

FIG. 6

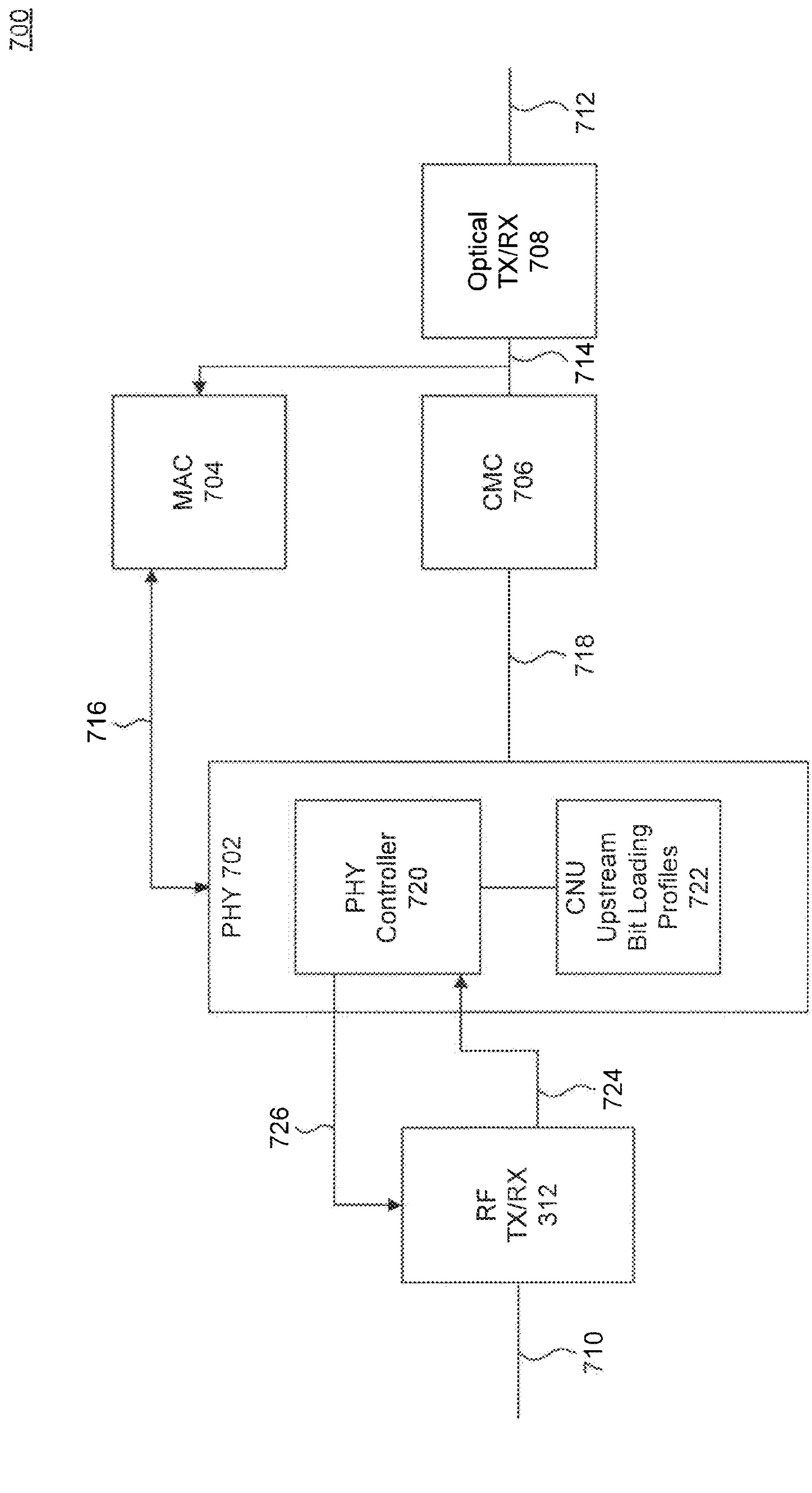
700
712
Optical TX/RX 708
714
MAC 704
CMC 706
716
718
PHY 702
PHY Controller 720
CNU Upstream Bit Loading Profiles 722
726
724
RF TX/RX 312
710

FIG. 7

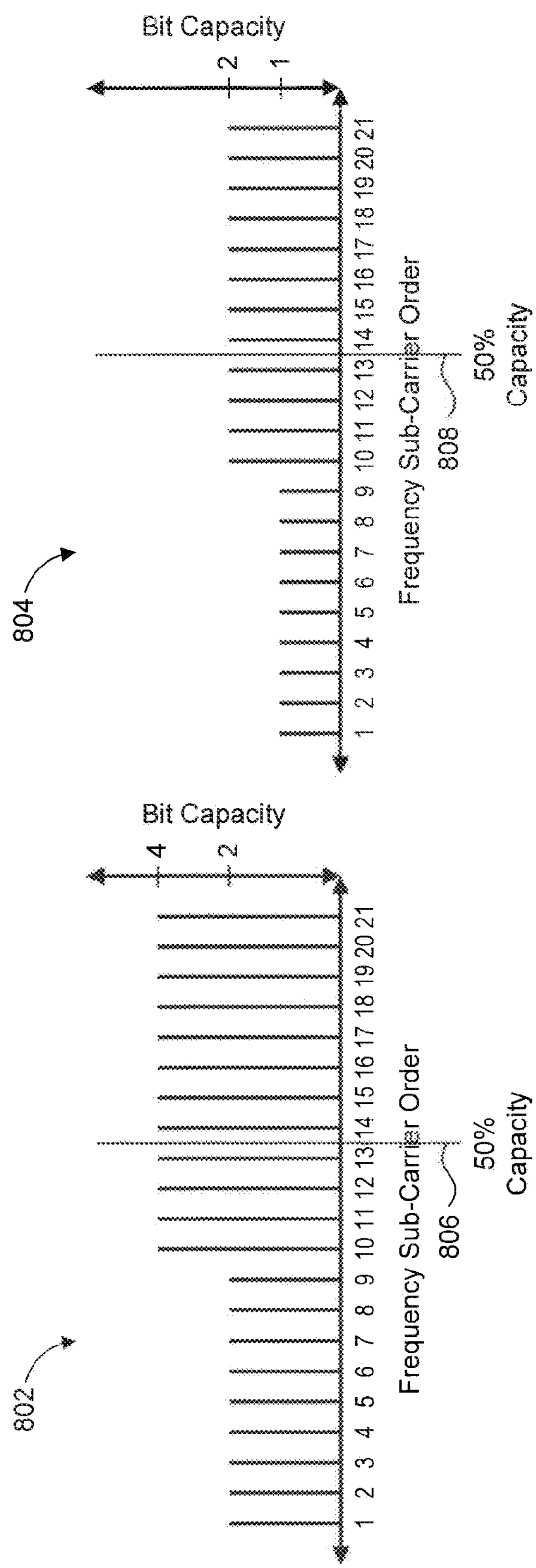
804
Bit Capacity
2
1
Frequency Sub-Carrier Order
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
808
50%
Capacity
802
Bit Capacity
4
2
Frequency Sub-Carrier Order
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
806
50%
Capacity

FIG. 8A

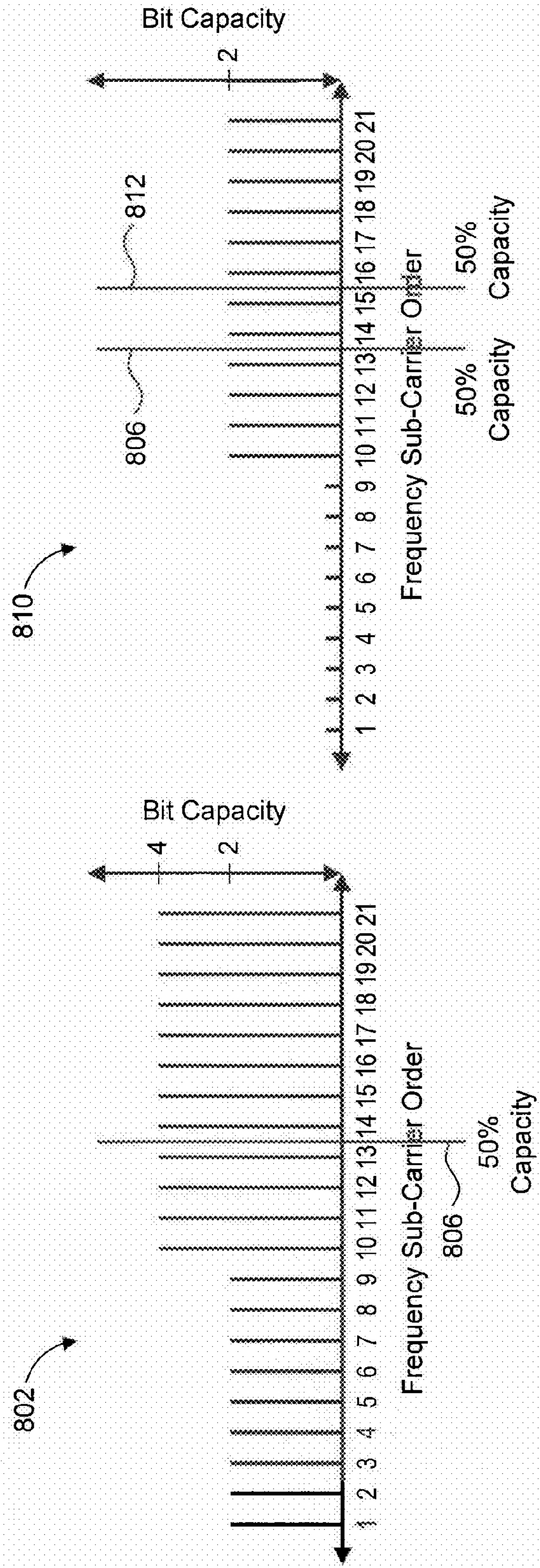
810
802
Bit Capacity
2
4
812
806
50% Capacity
Frequency Sub-Carrier Order
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

FIG. 8B

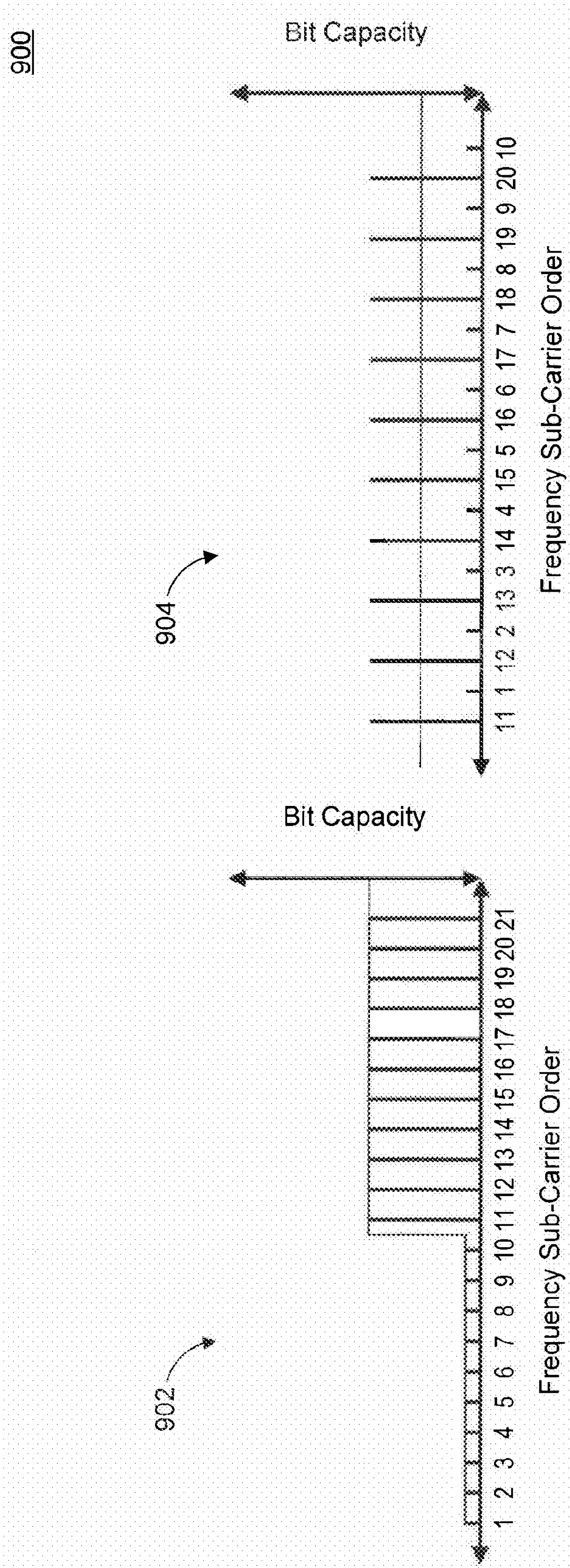
900
Bit Capacity
904
11 1 12 2 13 3 14 4 15 5 16 6 17 7 18 8 19 9 20 10
Frequency Sub-Carrier Order
Bit Capacity
902
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Frequency Sub-Carrier Order

FIG. 9

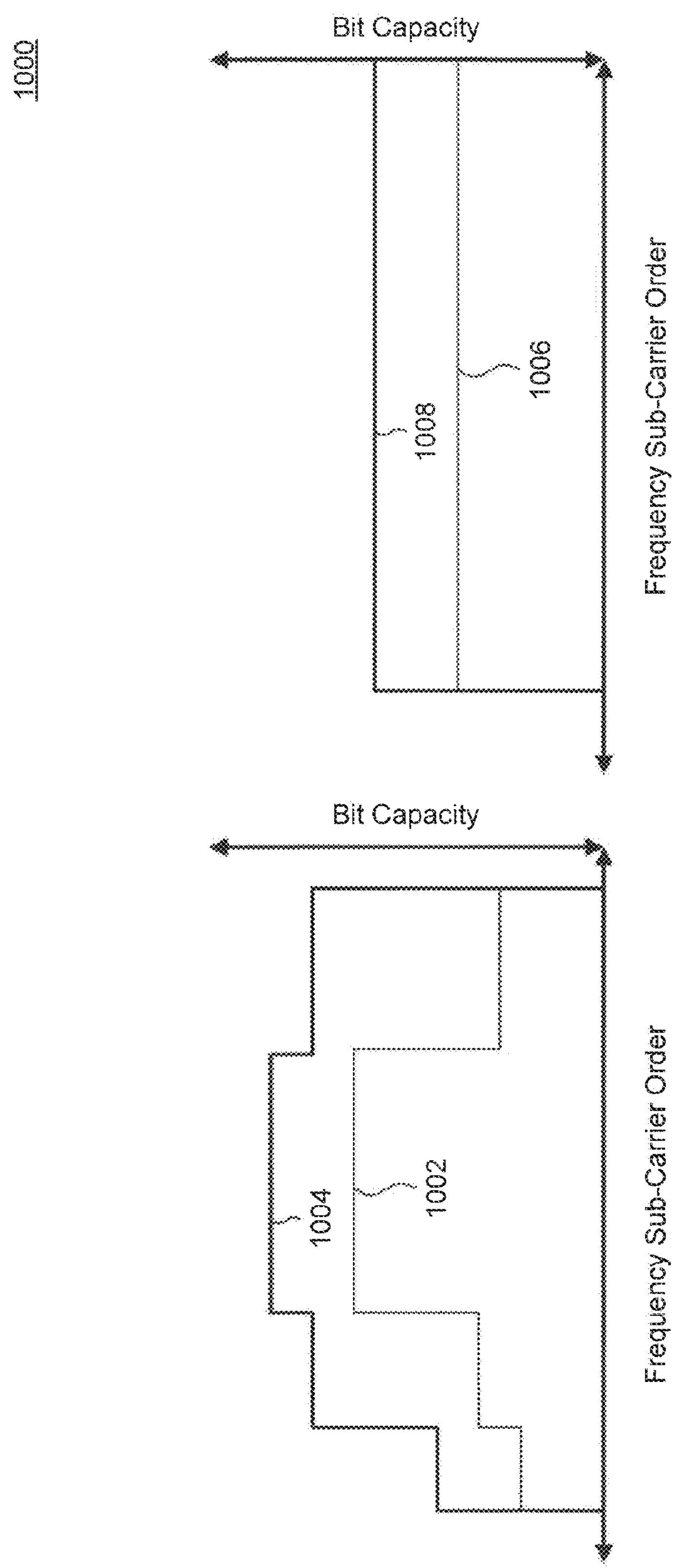
1000
Bit Capacity
1008
1006
Frequency Sub-Carrier Order
Bit Capacity
1004
1002
Frequency Sub-Carrier Order

FIG. 10

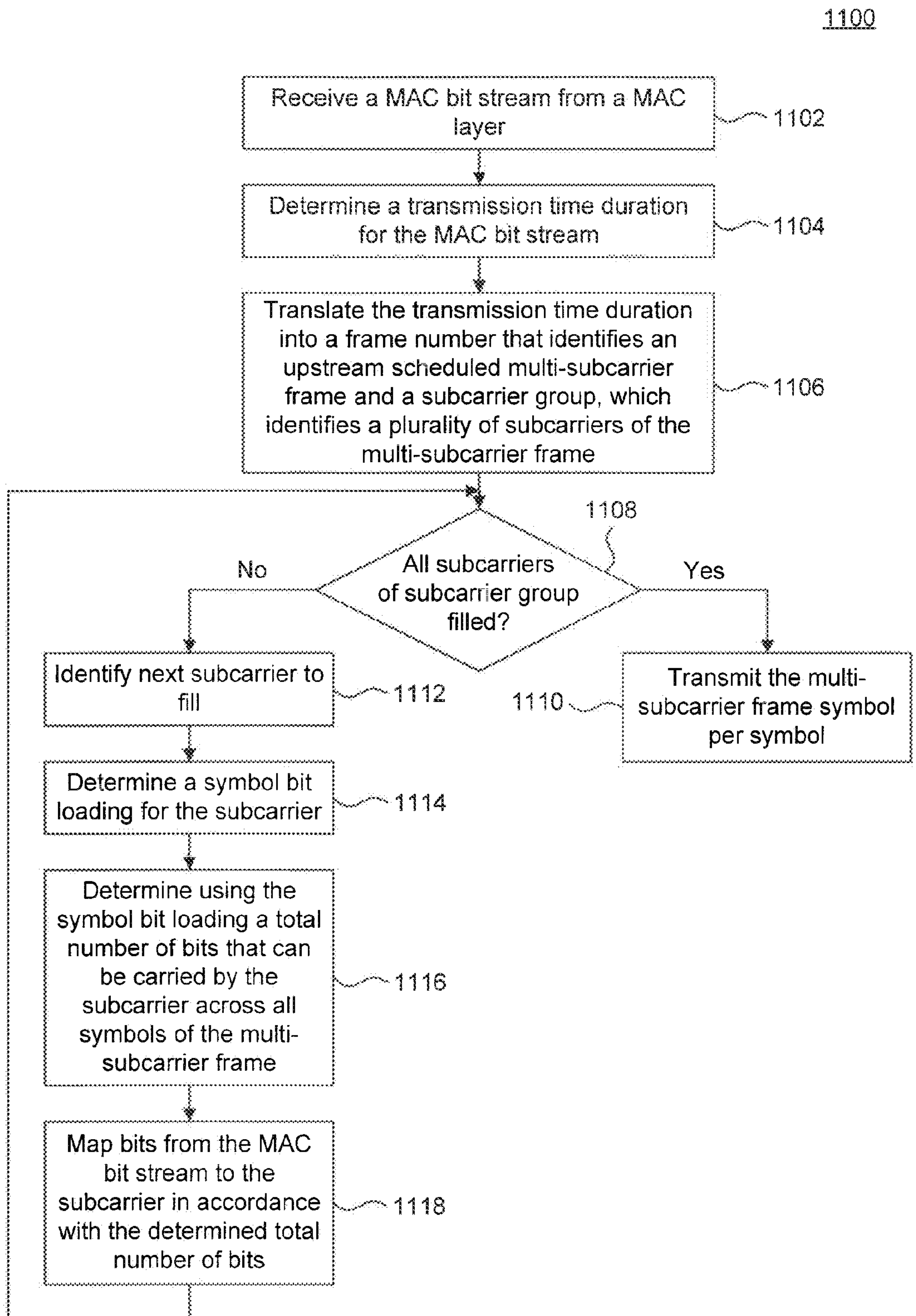
1100
Receive a MAC bit stream from a MAC layer
1102
Determine a transmission time duration for the MAC bit stream
1104
Translate the transmission time duration into a frame number that identifies an upstream scheduled multi-subcarrier frame and a subcarrier group, which identifies a plurality of subcarriers of the multi-subcarrier frame
1106
1108
No
All subcarriers of subcarrier group filled?
Yes
Identify next subcarrier to fill
1112
1110
Transmit the multi-subcarrier frame symbol per symbol
Determine a symbol bit loading for the subcarrier
1114
Determine using the symbol bit loading a total number of bits that can be carried by the subcarrier across all symbols of the multi-subcarrier frame
1116
Map bits from the MAC bit stream to the subcarrier in accordance with the determined total number of bits
1118

FIG. 11

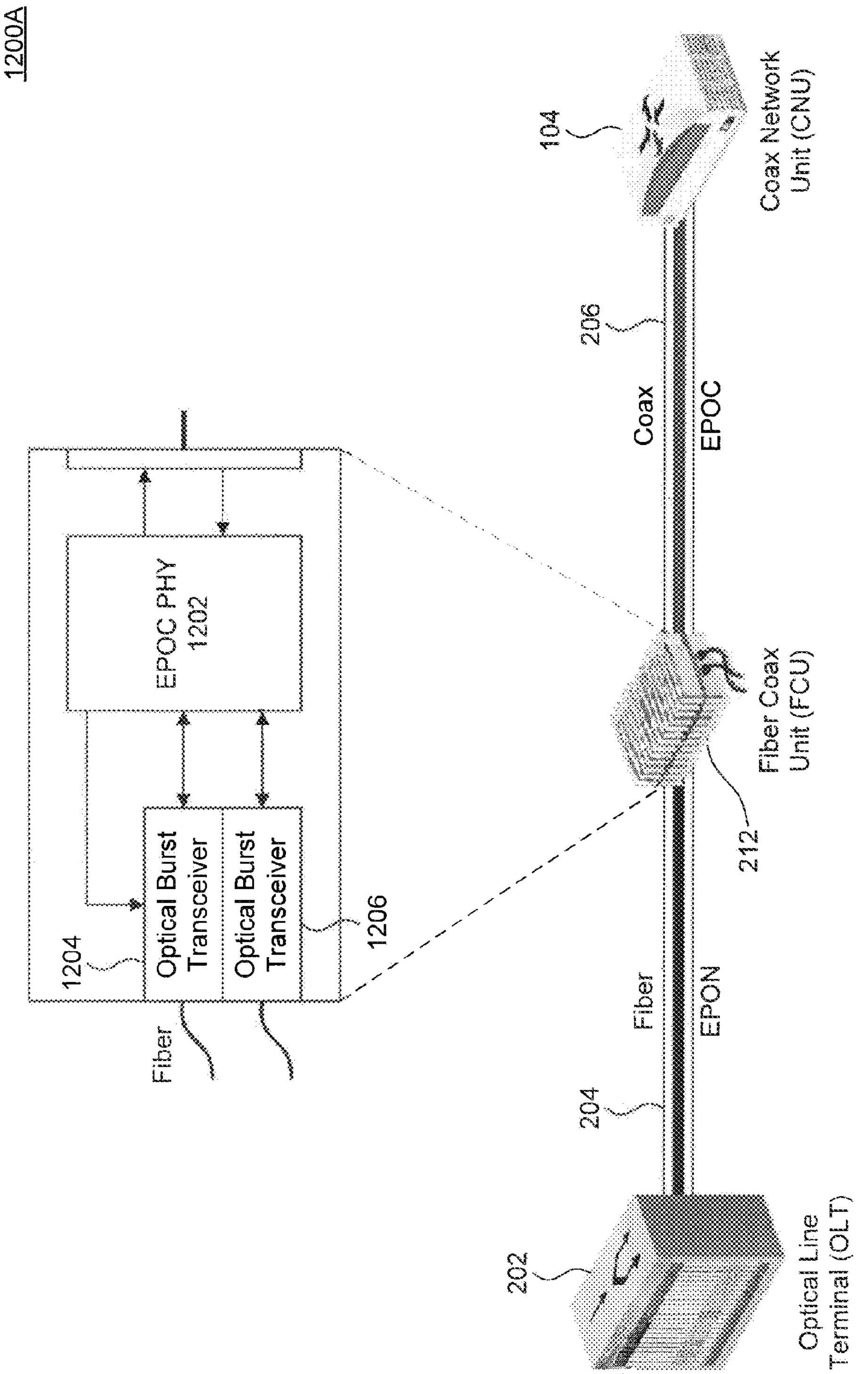
1200A
104
Coax Network Unit (CNU)
206
Coax
EPOC
EPOC PHY 1202
Optical Burst Transceiver
Optical Burst Transceiver
1204
1206
Fiber
Fiber Coax Unit (FCU)
212
Fiber
EPON
204
202
Optical Line Terminal (OLT)

FIG. 12A

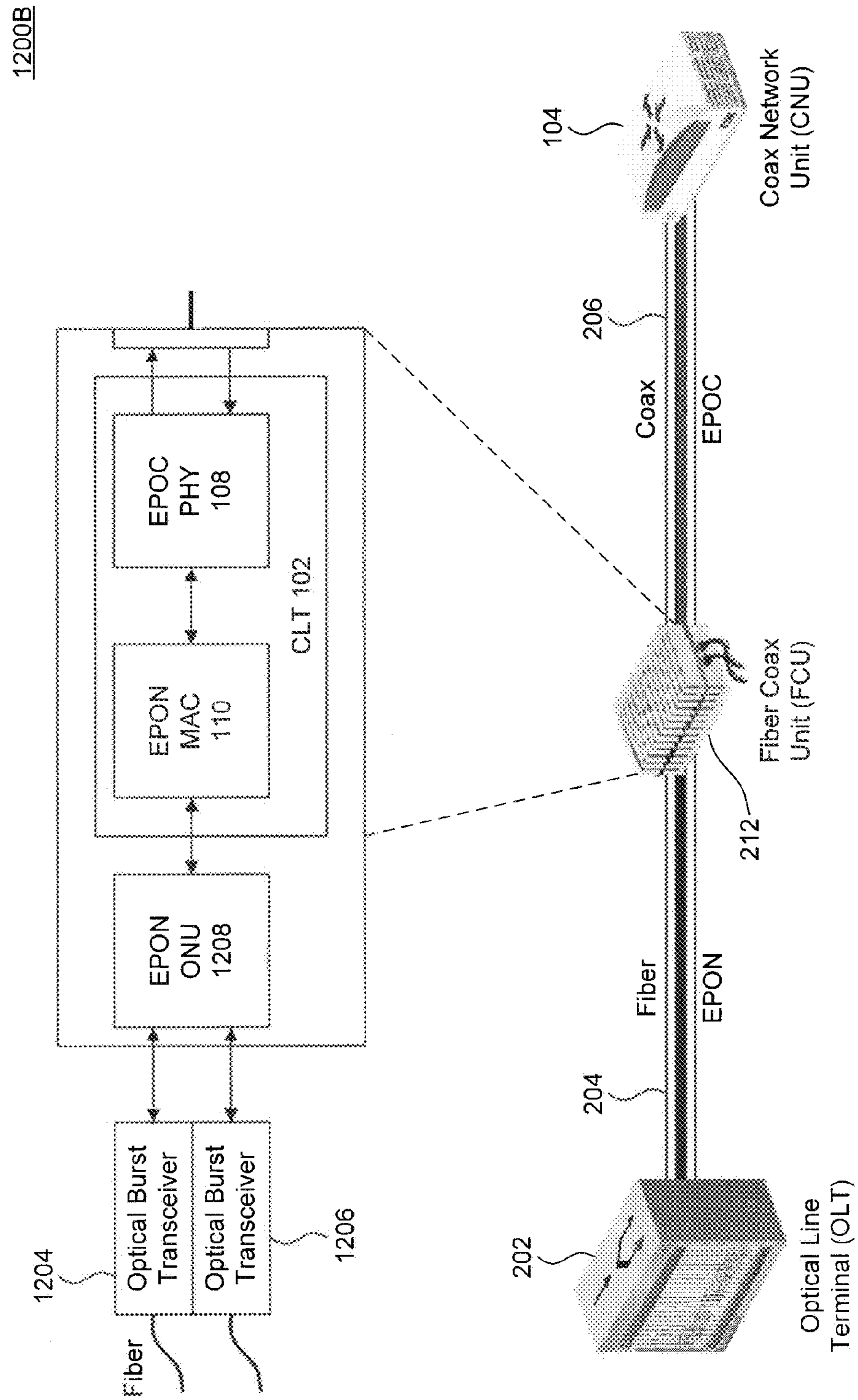
1200B
Fiber
1204
Optical Burst Transceiver
Optical Burst Transceiver
1206
EPON ONU 1208
EPON MAC 110
EPOC PHY 108
CLT 102
202
Optical Line Terminal (OLT)
204
Fiber
EPON
212
Fiber Coax Unit (FCU)
206
Coax
EPOC
104
Coax Network Unit (CNU)

FIG. 12B

# TIME TO TIME-FREQUENCY MAPPING AND DEMAPPING FOR ETHERNET PASSIVE OPTICAL NETWORK OVER COAX (EPOC)

## CROSS-REFERENCE TO RELATED APPLICATION(S)

The present application claims the benefit of U.S. Provisional Application No. 61/702,108, filed Sep. 17, 2012, U.S. Provisional Application No. 61/702,113, filed Sep. 17, 2012, U.S. Provisional Application No. 61/702,144, filed Sep. 17, 2012, and U.S. Provisional Application No. 61/724,399, filed Nov. 9, 2012, all of which are incorporated herein by reference in their entireties.

## TECHNICAL FIELD

The present disclosure relates generally to Ethernet Passive Optical Network over Coax (EPoC), and more particularly to time to time-frequency mapping/demapping and upstream bit loading profile balancing for Orthogonal Frequency Division Multiple Access (OFDMA) support.

## BACKGROUND

### Background Art

In a hybrid fiber-coax (HFC) network, the Medium Access Control (MAC) level upstream multi-access method may be different than the physical layer (PHY) level upstream multi-access method over the Ethernet Passive Optical Network over Coax (EPoC) portion of the network. For example, at the MAC level, upstream access is typically based on Ethernet Passive Optical Network (EPON) Time Division Multiple Access (TDMA). At the PHY level, however, a multi-subcarrier multiple access technique, such as Orthogonal Frequency Division Multiple Access (OFDMA) may be used.

## BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate the present disclosure and, together with the description, further serve to explain the principles of the disclosure and to enable a person skilled in the pertinent art to make and use the disclosure.

FIG. **1** illustrates an example cable network architecture according to an embodiment.

FIG. **2** illustrates another example cable network architecture according to an embodiment.

FIG. **3** illustrates an example coaxial network unit (CNU) according to an embodiment.

FIG. **4** is an example that illustrates an Orthogonal Frequency Division Multiple Access (OFDMA) framing approach according to an embodiment.

FIG. **5** is an example that illustrates upstream burst alignment according to an embodiment.

FIG. **6** is an example that illustrates the end-to-end transport of a Medium Access Control (MAC) frame from a Coaxial Network Unit (CNU) to a Coaxial Line Terminal (CLT) according to an embodiment.

FIG. **7** illustrates an example CLT according to an embodiment.

FIG. **8**A illustrates example upstream bit loading profiles for CNUs according to an embodiment.



FIG. **8**B illustrates example upstream bit loading profiles for CNUs according to an embodiment.

FIG. **9** is an example that illustrates capacity balancing of an upstream bit loading profile according to an embodiment.

FIG. **10** is an example that illustrates capacity balancing of multiple upstream bit loading profiles according to an embodiment.

FIG. **11** illustrates an example process according to an embodiment.

FIG. **12**A illustrates another example cable network architecture according to an embodiment.

FIG. **12**B illustrates another example cable network architecture according to an embodiment.

The present disclosure will be described with reference to the accompanying drawings. Generally, the drawing in which an element first appears is typically indicated by the leftmost digit(s) in the corresponding reference number.

## DETAILED DESCRIPTION OF EMBODIMENTS

For purposes of this discussion, the term "module" shall be understood to include at least one of software, firmware, and hardware (such as one or more circuits, microchips, processors, or devices, or any combination thereof), and any combination thereof. In addition, it will be understood that each module can include one, or more than one, component within an actual device, and each component that forms a part of the described module can function either cooperatively or independently of any other component forming a part of the module. Conversely, multiple modules described herein can represent a single component within an actual device. Further, components within a module can be in a single device or distributed among multiple devices in a wired or wireless manner.

FIG. **1** illustrates an example cable network architecture **100** according to an embodiment. Example cable network architecture **100** is provided for the purpose of illustration only and is not limiting of embodiments. Embodiments described herein can be implemented in a cable network architecture, such as cable network architecture **100**.

As shown in FIG. **1**, example network architecture **100** includes a CLT **102** and a CNU **104**, coupled via a distribution network **106**. Distribution network **106** can include a coaxial cable and optionally other coaxial components (e.g., splitters, amplifiers, etc.). As would be understood by a person of skill in the art based on the teachings herein, CLT **102** can serve multiple CNUs, such as CNU **104**, in a point-to-multipoint topology.

CLT **102** and CNU **104** implement respective Medium Access Control (MAC) layers **110** and **114**. According to embodiments, MAC layers **110** and **114** can be, without limitation, Data Over Cable Service Interface Specification (DOCSIS) or Ethernet Passive Optical Network (EPON) MAC layers. An end-to-end MAC link can be established between MAC layers **110** and **114** as shown in FIG. **1**.

CLT **102** and CNU **104** implement physical layers (PHYs) **108** and **112** respectively. PHYs **108** and **112** establish a PHY link over distribution network **106**, which can be transparent to upper layers such as the MAC layer. PHYs **108** and **112**, can be, without limitation, Ethernet Passive Optical Network over Coax (EPoC) PHYs. In an embodiment, PHY **108** includes a service provider PHY and PHY **112** includes a subscriber PHY.

FIG. **2** illustrates another example cable network architecture **200** according to an embodiment. Example cable network architecture **200** is provided for the purpose of illustration only and is not limiting of embodiments. Embodiments described herein can be implemented in a cable network architecture, such as cable network architecture **200**. Cable network architecture **200** is a hybrid fiber coaxial (HFC) architecture.

As shown in FIG. **2**, example cable network architecture **200** includes an Optical Line Terminal (OLT) **202**, which is coupled via a fiber optic line **204**, to a Fiber Coax Unit (FCU) **212**. FCU **212** is coupled via a coaxial cable **206**, and an intervening splitter **208**, to CNU **104** and a CNU **210**. FCU **212** can have different configurations according to embodiments, two of which are described in example architectures **1200**A and **1200**B of FIGS. **12**A and **12**B.

In example architecture **1200**A illustrated in FIG. **12**A, FCU **212** is in a managed repeater configuration and includes an EPoC PHY **1202**, an optical burst transceiver **1204**, and optical burst transceiver **1206**. FCU **212** can also include in this configuration an EPON MAC (not shown), which can be used for management. In this configuration, FCU **212** serves to convert at the PHY level between optical and coax. In an embodiment, FCU **212** includes a media converter for converting signals at the PHY level from optical to electrical, and vice versa. According to this configuration, an upstream transmission request from a CNU, such as CNU **104**, is received by FCU **212**, converted from coax to optical, and then transmitted to OLT **202**. OLT **202** issues an EPON time grant in response to the request. The EPON time grant is converted from optical to coax at FCU **212** and then forwarded to CNU **104**, which then transmits in the upstream in accordance with the EPON time grant.

In example architecture **1200**B illustrated in FIG. **12**B, FCU **212** is in a bridge configuration and includes a CLT **102** and an EPON ONU **1208**. CLT **102**, as described above in FIG. **1**, includes an EPON MAC **110** and an EPoC PHY **108**. EPON ONU **1208** includes an EPON MAC and is used to establish a MAC link between OLT **202** and FCU **212**. In this configuration, the EPON time grant issuance to the CNUs occurs at FCU **212**, particularly at EPON MAC **110**. Specifically, an upstream transmission request from a CNU, such as CNU **104**, is received by CLT **102** of FCU **212**. EPON MAC **110** of CLT **102** issues an EPON time grant in response to the request, and the EPON time grant is sent to CNU **104**. Subsequently, CNU **104** sends data in the upstream in accordance with the issued EPON time grant. The upstream data is received by EPON MAC **110** of CLT **102** and then forwarded to EPON ONU **1208** of FCU **212**. EPON ONU **1208** can then request an upstream transmission request from OLT **202**, in order to deliver this upstream data to OLT **202**.

Returning to FIG. **2**, OLT **202** can serve multiple ONUs (not shown in FIG. **2**), including EPON ONU **1208** of FCU **212**, over the EPON portion of the network. For example, the multiple ONUs can share a portion of fiber **204** to communicate with OLT **202**. In EPON/EPoC, the multiple ONUs share the upstream using a Time Division Multiple Access (TDMA) method, in which OLT **202** assigns each ONU a time slot in which to transmit its upstream data (upstream EPON time grant). A guard band time is typically used between upstream transmissions of different ONUs to avoid overlap of transmissions at OLT **202**. In order to minimize this guard band time (and increase the upstream bandwidth), OLT **202** uses a ranging protocol to determine the round trip delay time (RTT) between itself and each of the ONUs and grants upstream transmission times for ONUs in accordance with the determined RTTs.

CNUs **104** and **210** share the upstream channel to FCU **212**. Specifically, CNUs **104** and **210** use an Orthogonal Frequency Division Multiple Access (OFDMA) technique, which allows them to share the same OFDMA symbol or OFDMA frame (the OFDMA frame includes multiple time consecutive OFDMA symbols) to FCU **212**. In an embodiment, a particular CNU upstream transmission (or burst) can use individual subcarriers over a portion or all the symbols in the OFDMA frame.

But with the EPON and EPoC portions of the network using different upstream access methods, a translation function is needed. For example, to transmit a data burst from CNU **104** over the EPoC portion, there is a need to translate (map) an EPON upstream time grant assigned by OLT **202** (in example architecture **1200**A) or by CLT **102** (in example architecture **1200**B) to OFDMA resources represented by individual subcarriers of an upstream OFDMA frame. For upstream transmission of the same data burst from FCU **212** to OLT **202**, the upstream resources need to be identified and demodulated by FCU **212** to re-generate the data burst for TDMA transmission to OLT **202**. In addition, with FCU **212** supporting multiple CNUs, such as CNUs **104** and **210**, the translation of upstream EPON time grants to OFDMA resources must not result in CNUs using overlapping subcarriers in the same OFDMA frame. Additionally, the CNU upstream transmissions must be timed appropriately in order for them to be received within the same upstream OFDMA frame at the FCU. Further, it is desirable that a given upstream OFDMA frame shared by multiple CNUs be used (i.e., its individual subcarriers be used) efficiently among the CNUs to increase the amount of data carried by the OFDMA frame.

Embodiments as further described below include, but are not limited to, systems and methods for enabling OFDMA (or any other multi-subcarrier multiple access technique) in the upstream in an EPoC network. For example, embodiments include systems and methods for translating EPON upstream time grants to OFDMA resources represented by individual subcarriers of an upstream OFDMA frame. In an embodiment, the translation of EPON upstream time grants to OFDMA resources ensures that CNUs sharing an OFDMA frame do not use overlapping subcarriers within the frame. Embodiments further include systems and methods for timing upstream transmissions by the CNUs in order for the transmissions to be received within the same upstream OFDMA frame at the FCU. Embodiments further include systems and methods for re-generating a data burst from OFDMA resources for TDMA transmission from the FCU to an OLT. Further, embodiments include systems and methods for efficiently allocating the subcarriers of a given OFDMA frame among multiple CNUs in order to increase the amount of data carried by frame.

FIG. **3** illustrates an example coaxial network unit (CNU) **300** according to an embodiment. Example CNU **300** is provided for the purpose of illustration only and is not limiting of embodiments. Example CNU **300** can be an embodiment of CNU **104** or CNU **210** described above in FIGS. **1** and **2**, and can be used, along with other similar CNUs, to form and transmit an upstream OFDMA frame to an FCU, such as FCU **212** for example.

As shown in FIG. **3**, example CNU **300** includes a MAC layer **302**, a PHY chip **304**, a radio frequency (RF) transceiver **312**. MAC layer **302** can be implemented in a chip or processor and can be an EPON MAC layer. MAC layer **302** is connected to PHY chip **304** via a MAC-PHY interface **306**. MAC-PHY interface **306** can be a media independent interface (MII), such as the 10 Gigabit MII (XGMII) interface. PHY chip **304** includes, among other components, a PHY controller **308** and an upstream bit loading profile **310**. RF transceiver **312** includes an RF transmitter and an RF receiver and is coupled to a coaxial cable **318**.

In an embodiment, PHY controller **308** is configured to receive a MAC bit stream **316** over MAC-PHY interface **306** from MAC layer **302**. MAC bit stream **316** can include one or more EPON MAC frames that represent a MAC data burst. MAC bit stream **316** can be transmitted by MAC layer **302** in response to an upstream EPON time grant, received by MAC layer **302** in response to an upstream transmission request to an OLT. In an embodiment, PHY controller **308** can determine the bit size of MAC bit stream **316** based on a start transmission time and an end transmission time of MAC bit stream **316** over MAC-PHY interface **306**.

PHY controller **308** is configured to determine a transmission time duration for MAC bit stream **316** over coaxial cable **318**. In an embodiment, PHY controller **308** determines the transmission time duration for MAC bit stream **316** based on the bit size of MAC bit stream **316** and upstream bit loading profile **310**. Upstream bit loading profile **310** determines for each available subcarrier of an OFDMA symbol (which is defined as a plurality of subcarriers for a defined OFDMA symbol time) the number of bits that can be carried by the subcarrier in one OFMDA symbol (subcarrier symbol bit loading) when used by CNU **300** to transmit to the FCU. Typically, subcarrier bit loading can vary from subcarrier to subcarrier (especially for subcarriers that are frequency distant) and from CNU to CNU (e.g., because CNUs can have different Signal-to-Noise Ratios (SNRs) at the FCU).

In an embodiment, PHY controller **308** determines a total bit carrying capacity of an OFDMA frame. The OFDMA frame includes multiple time consecutive OFDMA symbols having a defined symbol time duration. The number of OFDMA symbols in an OFDMA frame is configurable and may be between 8 and 32, for example. PHY controller **308** then divides the total bit carrying capacity of the OFDMA frame by the OFDMA frame duration to determine an average data transmission rate from CNU **300** to the FCU. PHY controller **308** then uses the average data transmission rate to compute the transmission time duration for MAC bit stream **316** based on the bit size of MAC bit stream **316**. In an embodiment, PHY controller **308** represents the transmission time duration for MAC bit stream **316** in terms of EPON Time Quantas (TQs) (each EPON TQ is equivalent to 16 nanoseconds).

PHY controller **308** is then configured to translate the transmission time duration for MAC bit stream **316** into an OFDMA frame number and a subcarrier group. In an embodiment, the frame number identifies an upstream scheduled OFDMA frame and the subcarrier group identifies a plurality of subcarriers of the upstream scheduled OFDMA frame. In an embodiment, upstream OFDMA frames are transmitted consecutively in time (with optionally an inter-frame gap (IFG)) to the FCU to form an upstream channel. Each upstream OFDMA frame has a frame number associated with it, which identifies the frame in time (i.e., identifies the frame start and end in time) to the FCU and each of the CNUs. As further described below, the subcarrier group can correspond to consecutive or non-consecutive subcarriers (in terms frequency) of the OFDMA frame. Thus, a frame number (e.g., frame #**200**) and a subcarrier group (e.g., subcarriers **100**-**150**) within the frame identified by the frame number indicate unique OFDMA resources of the upstream channel to the FCU.

In an embodiment, PHY controller **308** is configured to translate the transmission time duration into the frame number and the subcarrier group based at least in part on the start transmission time of MAC bit stream **316** over MAC-PHY interface **306**. In an embodiment, PHY controller **308** uses a translation function that implements a one-to-one mapping of start transmission times to upstream OFDMA resources (i.e., no two different start transmission times can result in same or overlapping OFDMA resources). In an embodiment, MAC layer **302** is synchronized with a MAC layer of the serving OLT (e.g., example architecture **1200**A) or the CLT (e.g., example architecture **1200**B), such that no two CNUs served by the OLT or CLT can have the same start transmission times over their respective MAC-PHY interfaces. As a result, the translation of the transmission time duration based on the start transmission time of MAC bit stream **316** over MAC-PHY interface **306** results in upstream OFDMA resources which can only be determined by example CNU **300**.

Having identified the upstream OFDMA resources to carry MAC bit stream **316**, PHY controller **308** is configured to map MAC bit stream **316** to the determined subcarrier group of the identified upstream OFDMA frame. In an embodiment, PHY controller **308** is configured to map MAC bit stream **316** to the subcarrier group based on upstream bit loading profile **310**, assigning to each subcarrier of the subcarrier group a number of bits of MAC bit stream **316** in accordance with the symbol bit loading of the subcarrier as determined in upstream bit loading profile **310**. PHY controller **308** then outputs an output signal **320** to RF transceiver **312**. Output signal **320** includes, for each subcarrier of the subcarrier group, the bits mapped to the subcarrier for the next OFDMA symbol (of the OFDMA frame) to be transmitted. In an embodiment, RF transceiver **312** includes an Inverse Fast Fourier Transform (IFFT) module, which modulates each subcarrier of the subcarrier group with the respective bits mapped to it. The resulting modulated subcarriers form the OFDMA symbol to be transmitted. The same process is repeated for each OFDMA symbol in the OFDMA frame. In another embodiment, PHY controller **308** is further configured to configure RF transceiver **312** using a control signal **314** to transmit during the identified upstream OFDMA frame and on the identified subcarrier group over coaxial cable **318**.

FIG. **4** is an example **400** that illustrates an OFDMA framing approach according to an embodiment. Example **400** is provided for the purpose of illustration only and is not limiting of embodiments. Example **400** shows two upstream OFDMA frames (OFDMA Frame **1** and OFDMA Frame **2**) being transmitted consecutively in time. In an embodiment, an IFG separates consecutive OFDMA frames. Each OFDMA frame includes 12 OFDMA symbols, though the OFDMA frame can be configured to include any number of OFDMA symbols according to embodiments.

OFDMA frames are transmitted OFDMA symbol by OFDMA symbol. However, the mapping of bits (e.g., MAC bit stream **316**) to OFDMA frames is done subcarrier per subcarrier as illustrated by the arrows shown in FIG. **4**. For example, assuming that subcarriers are filled in an ascending order of frequency, then bits are mapped to a first subcarrier **402** across all OFDMA symbols of the OFDMA frame, before the mapping of bits to a second subcarrier **404** is performed. This mapping approach ensures that any given data codeword (e.g., Forward Error Correction (FEC) protected data block) of the MAC bit stream is spread over multiple OFDMA symbols, which reduces the effects of burst noise on any transmitted data codeword. In another embodiment, one or more OFDMA symbols in a given OFDMA frame are designated as SYNC symbols and are configured to carry a mixture of data and pilot information. The pilot information can be used by the FCU to estimate the upstream channels from the CNUs.

Returning to FIG. **3**, in an embodiment, example CNU **300** can be configured to implement the OFDMA framing approach illustrated in FIG. **4**. Accordingly, PHY controller

308 can be configured, for each subcarrier of the identified subcarrier group, to: determine a symbol bit loading for the subcarrier from upstream bit loading profile 310; determine, using the symbol bit loading, a total number of bits that can be carried by the subcarrier across the multiple time consecutive symbols of the OFDMA frame; and map bits from MAC bit stream 316 to the subcarrier in accordance with the total number of bits. In an embodiment, PHY controller 308 maps the bits from MAC bit stream 316 to internal registers, each corresponding to a particular subcarrier. Then, for each OFDMA symbol, PHY controller 308 outputs an appropriate number of bits from each of the internal registers (according to the symbol bit loading of the respective subcarrier) using output signal 320 to RF transceiver 312.

As described above, in addition to ensuring that CNUs served by the same FCU use non-overlapping subcarriers in an OFDMA frame, transmissions by the CNUs must be timed appropriately such that they arrive and can be received within the same upstream OFDMA frame at the FCU. With OFDMA frames having boundaries that are defined both in time and frequency by the FCU, each CNU must maintain a local OFDMA frame start time (which identifies, for example, the start of the next upstream OFDMA frame). As CNUs can be located at different distances from the FCU, the OFDMA frame start time for the same OFDMA frame can be different from one CNU to another, with the difference accounting for the difference in propagation time to reach the shared medium. This is illustrated in example 500 of FIG. 5, which illustrates upstream burst alignment according to an embodiment. Example 500 is provided for the purpose of illustration only and is not limiting of embodiments. For simplification purposes only, example 500 is described with reference to example cable network architecture 200.

As shown in FIG. 5, CNU 104 and CNU 210 are both served by FCU 212 using a shared coaxial cable 206. For illustration, CNU 104 is assumed to be closer to FCU 212 than CNU 210 (e.g., CNU 104 is connected to splitter 208 via a shorter coaxial cable than CNU 210). In order for CNUs 104 and 210 share a same upstream OFDMA frame 502 to FCU 212 for respective bursts, CNUs 104 and 210 must transmit on non-overlapping resources 504 and 506, respectively, of OFDMA frame 502. In addition, CNU 210 must begin its burst transmission before CNU 104 such that the two transmissions align in time at splitter 208. Splitter 208 can combine the two transmissions onto coaxial cable 206 to form upstream OFDMA frame 502.

In an embodiment, FCU 212 assists each of CNUs 104 and 210 to determine their respective local OFDMA frame start times to align their transmissions in time at the first component of the shared upstream medium (splitter 208 in example 500). In an embodiment, to calibrate its respective local OFDMA frame start time, a CNU (e.g., via PHY controller 308) is configured to transmit a signal on an upstream control channel according to its local OFDMA frame start time. The upstream control channel can be transmitted on a fixed set of subcarriers outside of the data channel carrying the OFDMA frame. In an embodiment, the CNU begins transmitting the signal at its local OFDMA frame start time. When FCU 212 receives the signal on the upstream control channel, it computes a time offset between the time that the signal was received and the time that the start of the corresponding upstream OFDMA frame was received. FCU 212 then sends the time offset to the CNU on a downstream control channel. The downstream control channel can be transmitted on a fixed set of subcarriers outside of the downstream data channel. The CNU is configured to receive the time offset on the downstream control channel and to adjust the local frame start time using the time offset. By adjusting its local frame start time using the time offset, the CNU can ensure that its upstream transmissions align with the FCU defined OFDMA frame boundary.

In addition to ensuring time alignment at the PHY level such that the FCU PHY (e.g., EPoC PHY 1202 or 108) receives CNU upstream transmissions within defined OFDMA frame boundaries, embodiments are transparent to the MAC layer such that neither the CNU MAC nor the FCU MAC (e.g., EPON MAC 110) (nor the OLT EPON MAC) needs to be modified or made aware of the underlying translation of upstream EPON time grants to OFDMA resources. In an embodiment, to ensure that the MAC layers are not affected by the underlying PHY level translation, the CNU PHY maps MAC data to OFDMA resources based on a fixed delay and the FCU PHY (e.g., EPoC PHY 1202 or EPoC PHY 108) demodulates OFDMA resources and releases the resulting MAC data to the CLT MAC (e.g., EPON MAC 110) (e.g., in example architecture 1200B) or OLT MAC (e.g., in example architecture 1200A) based on a fixed delay. This results in a fixed end-to-end MAC frame delay between the CNU MAC and the CLT/OLT MAC. This is illustrated in FIG. 6 below.

FIG. 6 is an example that illustrates the end-to-end transport of MAC bit stream 316 from a CNU to a CLT according to an embodiment. MAC bit stream 316 can include one or more MAC frames, for example. As shown in FIG. 6, MAC bit stream 316 is placed by CNU MAC layer 302 on MAC-PHY interface 306. CNU PHY 304 maps MAC bit stream 316 to a subcarrier group 612 of an upstream OFDMA frame 614 and transmits the subcarrier group 612 over a coaxial cable 318 at a fixed delay 602 relative to when MAC bit stream 316 appeared on MAC-PHY interface 306. At the CLT, a CLT PHY 606 demodulates the subcarrier group 612 of OFDMA frame 614 to re-generate MAC bit stream 316. CLT PHY 606 then places MAC bit stream 316 on a MAC-PHY interface 610 for CLT MAC 608, at a fixed delay 604 relative to when OFDMA frame 614 was received. MAC bit stream 316 thus incurs a fixed end-to-end delay from CNU MAC layer 302 to CLT MAC 608, which ensures a constant data rate MAC link between the CNU and CLT.

FIG. 7 illustrates an example FCU 700 according to an embodiment. Example FCU 700 is provided for the purpose of illustration only and is not limiting of embodiments. Example FCU 700 can be an embodiment of FCU 212 described above in FIGS. 2, 12A, and 12B. As shown in FIG. 7, example FCU 700 includes a PHY chip 702, a MAC layer 704, a Coaxial Media Converter (CMC) 706, an RF transceiver 312, and an optical transceiver 708. In other embodiments, FCU 700 can include more or less components than shown in FIG. 7. For example, in accordance with example architecture 1200B, FCU 700 may not include CMC 706. In other embodiments, CMC 706 may be part of PHY chip 702, which along with MAC layer 704 can form a CLT, such as CLT 102.

MAC layer 704 can be implemented in a chip or processor and can be an EPON MAC layer. MAC layer 704 is connected to PHY chip 702 via a MAC-PHY interface 716. MAC-PHY interface 716 can be an XGMII interface. PHY chip 702 includes, among other components, a PHY controller 720 and CNU upstream bit loading profiles 722. CNU upstream bit loading profiles 722 include the upstream bit loading profiles for CNUs served by FCU 700. CMC 706 can be implemented as described in U.S. application Ser. No. 12/878,643, filed Sep. 9, 2010, which is incorporated herein by reference in its entirety. In an embodiment, CMC 706 performs PHY level conversion from EPON to EPoC, and vice versa. RF transceiver **312** includes an RF transmitter and an RF receiver and is coupled to a coaxial cable **710**. Coaxial cable **710** can connect FCU **700** to one or more CNUs. Optical transceiver **708** includes an optical transmitter and an optical receiver and is coupled to a fiber optic line **712**. Fiber optic line **712** can connect FCU **700** to an OLT, such as OLT **202**, for example.

In an embodiment, example FCU **700** can receive an upstream OFDMA frame over coaxial cable **710**. The upstream OFDMA frame can be formed from upstream transmissions of one or more CNUs as described above. For example, the upstream OFDMA frame can contain first and second upstream transmissions from first and second CNUs, such as CNUs **104** and **210**, to FCU **700**. The first and second transmissions are transmitted from the first and second CNUs at respective first and second upstream transmission times. The first and second upstream transmission times are provided to the first and second CNUs in respective first and second upstream EPON time grants, issued by an OLT (e.g., OLT **202** in example architecture **1200**A) or by FCU **700** (by MAC layer **704**) and delivered to the first and second CNUs by FCU **700**.

RF transceiver **312** is configured to receive a signal that carries the upstream OFDMA frame over coaxial cable **710** and to provide an output signal **724** that represents the upstream OFDMA frame to PHY controller **720**. In an embodiment, PHY controller **720** controls RF transceiver **312** using a control signal **726** in order to locate the upstream OFDMA frame in time and frequency.

PHY controller **720** is configured to act on output signal **724**, which includes the upstream OFDMA frame, to identify, a first subcarrier group of the OFDMA frame carrying the first transmission from the first CNU. In an embodiment, PHY controller **720** identifies a start marker and an end marker associated with the first subcarrier group. In an embodiment, the start marker corresponds to a first subcarrier of the first subcarrier group and is filled by a sequence of bits that can be identified by PHY controller **720** of FCU **700**. The end marker corresponds to the last subcarrier of the first subcarrier group and is filled by a sequence of bits that can be identified by PHY controller **720** of FCU **700**. PHY controller **720** then generates a bit stream **718** using the first subcarrier group.

In an embodiment, as described above, the upstream OFDMA frame includes time consecutive OFDMA symbols. Accordingly, PHY controller **720** is further configured, for each subcarrier of the first subcarrier group, to determine a symbol bit loading for the subcarrier from an upstream bit loading profile of the first CNU (located in CNU upstream profiles **722**), and to demodulate the subcarrier, using the symbol bit loading, over the multiple time consecutive OFDMA symbols of the OFDMA frame to generate a bit sequence for the subcarrier. PHY controller **720** then appends the bit sequences generated by demodulating the subcarriers of the first subcarrier group to generate bit stream **718**. In an embodiment, PHY controller **720** eliminates the bits corresponding to the start and end markers in generating bit stream **718**.

In an embodiment, such as when FCU **700** is used in an architecture such as example architecture **1200**B, bit stream **718** is delivered over MAC-PHY interface **716** to MAC layer **704**. MAC layer **704** can then send an upstream transmission request to the OLT, in order to deliver the MAC data contained in bit stream **718** to the OLT.

In another embodiment, such as when FCU **700** is used in an architecture such as example architecture **1200**A, bit stream **718** is forwarded to CMC **706**. In an embodiment, CMC **706** can be part of PHY **702**. CMC **706** is configured to adapt bit stream **718** for optical transmission to generate an adapted bit stream **714**. In an embodiment, CMC **706** is configured to adjust a PHY level encoding (e.g., line encoding) of bit stream **718** to generate bit stream **714**. Optical transceiver **708** is configured to generate an optical signal using adapted bit stream **714** and to transmit the optical signal over fiber optical line **712** to the OLT.

As mentioned above, embodiments further include systems and methods for efficiently allocating the subcarriers of a given upstream OFDMA frame among multiple CNUs in order to increase the amount of data carried by the frame. In an embodiment, the allocation takes into account the upstream bit loading profiles of the multiple CNUs, such that CNUs use subcarriers with larger symbol bit loading whenever possible. In another embodiment, the subcarrier loading order (the order of subcarriers used by a CNU to map a bit stream to the subcarriers) used by one or more CNUs is adjusted for an upstream OFDMA frame based on the upstream loading profiles of CNUs transmitting during the upstream OFDMA frame. These embodiments are further described below with reference to FIGS. **8**A, **8**B, **9**, and **10**.

FIG. **8**A illustrates example upstream bit loading profiles for CNUs according to an embodiment. Specifically, FIG. **8**A shows a first upstream bit loading profile **802** and a second upstream bit loading profile **804**. First upstream bit loading profile **802** can be for a first CNU, such as CNU **104**, for example, and second upstream bit loading profile **804** can be for a second CNU, such as CNU **210**, for example. For the purpose of illustration only, it is assumed that first and second upstream bit loading profiles **802** and **804** include 21 subcarriers, numbered from 1 to 21, which correspond to the subcarriers of an OFDMA frame. As would be understood by a person of skill in the art, an OFDMA frame can include more than 21 subcarriers in practice. Subcarrier #**21** is assumed to be the lowest frequency subcarrier, followed by subcarrier #**20**, and so on until subcarrier #**1**, which is the highest frequency subcarrier.

First upstream bit loading profile **802** has a greater symbol bit loading per subcarrier than second upstream bit loading profile **804** for each of the subcarriers **1-21**. Specifically, for illustration, it is assumed that the symbol bit loading of first upstream bit loading profile **802**, for each subcarrier, is twice that of second upstream bit loading profile **804**. For example, for subcarrier #**1**, the symbol bit loading is 2 bits per symbol in first upstream bit loading profile **802** and 1 bit per symbol in second upstream bit loading profile **804**. Similarly, for subcarrier #**10**, the symbol bit loading is 4 bits per symbol in first upstream bit loading profile **802** and 2 bits per symbol in second upstream bit loading profile **804**. Accordingly, the first CNU can load twice as many bits in the OFDMA frame than the second CNU if each CNU were to use the OFDMA frame exclusively.

Because first and second upstream bit loading profiles **802** and **804** are proportional to each other (related by a 2 to 1 ratio in terms of symbol bit loading per subcarrier), if the subcarriers **1-21** are filled in order (e.g., from the lowest frequency subcarrier to the highest frequency subcarrier, or vice versa) any given OFDMA frame usage capacity percentage will be reached at the same subcarrier location within the OFDMA frame using both first and second upstream bit loading profiles **802** and **804**. For example, as shown in FIG. **8**A, using first upstream bit loading profile **802**, if subcarriers are filled consecutively starting from subcarrier #**1**, the OFDMA frame will reach 50% usage capacity (i.e., the OFDMA frame will be half full) once subcarrier #**13** is filled as illustrated by 50% capacity line **806**. Similarly, the 50% capacity line **808** for second upstream bit loading profile **804** occurs once subcarrier #**13** is filled.

Because of this alignment of capacity usage percentage lines between first and second upstream profiles **802** and **804** (due to them being proportional), the first and second CNUs can be readily accommodated within the same OFDMA frame. For example, if the first and second CNUs each requested an upstream transmission equivalent to 50% capacity of an OFDMA frame, then the first CNU can use a first half (of the subcarriers) of the OFDMA frame and the second CNU can use the other half of the OFDMA frame. Similarly, if the first CNU had requested 20% of the capacity of an OFDMA frame and the second CNU had requested 30% of the capacity of the OFDMA frame, then the first CNU can use, for example, the lowest frequency subcarriers in the frame until the 20% capacity line is reached and the second CNU can use the next set of subcarriers until the 50% capacity line is reached.

In practice, however, upstream bit loading profiles of CNUs transmitting within the same OFDMA frame are not always proportional or substantially proportional as illustrated in FIG. **8**A. For example, as shown in FIG. **8**B, a first CNU and a third CNU transmitting in the same OFDMA frame can have respectively first upstream bit loading profile **802** and a third upstream bit loading profile **810**. Third upstream bit loading profile **810** has nulled subcarriers at subcarriers **1** through **9**. As a result, upstream bit loading profiles **802** and **810** have distributions that are not proportional, and their respective capacity usage percentage lines do not match. For example, using first upstream bit loading profile **802**, if subcarriers are filled consecutively starting from subcarrier #**1**, the OFDMA frame will reach 50% usage capacity once subcarrier #**13** is filled as illustrated by 50% capacity line **806**. In contrast, the 50% capacity line **812** using third upstream bit loading profile **810** is only reached after subcarrier #**15** is filled.

Because of this misalignment of capacity percentage lines between first and third upstream profiles **802** and **810**, the first and third CNUs are more difficult to accommodate within the same OFDMA frame. For example, if both the first and third CNUs request an upstream transmission equivalent to 50% capacity of an OFDMA frame, then the loading order of subcarriers can determine whether or not both CNUs can be accommodated in the same frame. For example, if subcarriers are filled consecutively starting from subcarrier #**1** beginning with the third CNU, then the third CNU will use subcarriers **1**-**15**. The remaining subcarriers **16**-**21** however do not provide the first CNU a 50% capacity because the 50% capacity line **806** for first upstream profile **802** is before subcarrier #**15**. Accordingly, the first CNU transmission cannot be fully accommodated within the same OFDMA frame and additional overhead is needed in order to spread the first CNU transmission over multiple OFDMA frames.

Embodiments as further described below can be used to alleviate this problem. Specifically, in an embodiment, the upstream bit loading profile of a CNU can be capacity balanced by adjusting the order in which subcarriers are filled by the CNU. This is illustrated in FIG. **9**, which shows the capacity balancing of an upstream bit loading profile **902**.

As shown in FIG. **9**, bit loading profile **902** is unbalanced with subcarriers **1**-**10** being nulled and unable to carry any bits, and subcarriers **11**-**20** each having a certain bit loading. Because of this unbalance, the CNU can only use subcarriers **11**-**20** or a portion thereof for any upstream transmission, which constrains the use of the subcarriers between multiple CNUs and may cause overlap between CNUs. For example, if an upstream time grant of a given start time and length (in TQs) is mapped to frequency according to profile **902**, then the start time may map to some of subcarriers **1**-**10**. However, because the CNU cannot transmit any bits on those subcarriers, it may end up transmitting on the subcarriers starting with subcarrier #**11**. However, this may overlap with a transmission of another CNU with the same profile and a different start time. This problem can be resolved according to two different embodiments as further described below.

In one embodiment, bit loading profile **902** can be capacity balanced by adjusting the order of subcarriers within the profile to generate a capacity balanced bit loading profile **904**. Specifically, subcarriers **1**-**10** are interleaved with subcarriers **11**-**20** as shown in FIG. **9**, such that the bit loading is uniform over any two consecutive subcarriers of the profile. The CNU uses bit loading profile **904** according to the adjusted subcarrier loading order, for example filling subcarrier #**11**, then subcarrier #**1**, then subcarrier #**12**, and so on, or vice versa starting from subcarrier #**10**.

In another embodiment, suitable when the CNU(s) have similar bit loading profiles, a total number of bits per OFDMA frame (frame capacity) is calculated using the bit loading profile. Each CNU then maintains a buffer that is equivalent to the OFDMA frame (with equal capacity to the calculated frame capacity). For every OFDMA frame, each CNU fills the buffer (as if it was filling the OFDMA frame, i.e., subcarrier by subcarrier) with actual data, when it has upstream MAC data to send, and with null data, when it has no upstream MAC data to send. The CNUs fill their respective buffers in a time synchronized manner such that each CNU fills the same buffer element at the same time. Each CNU PHY then maps the contents of the buffer to subcarriers and only transmits those subcarriers filled with actual data from the buffer. Because the upstream time grants from the OLT/CLT are never overlapping, at any time only one CNU can be filling actual data to subcarriers while the other CNUs will be filling null data to the same subcarriers. Additionally, only the one CNU that filled actual data to the subcarriers transmits on the subcarriers during the OFDMA frame.

Capacity balancing can also be used even in situations in which the CNUs served by the FCU have proportional upstream bit loading profiles as described above in FIG. **8**A. For example, as shown in FIG. **10**, upstream bit loading profiles **1002** and **1004**, while proportional to each other, are unbalanced across subcarriers. The unbalance can complicate the allocation of subcarriers to the CNUs within the same OFDMA frame. In an embodiment, profiles **1002** and **1004** can be capacity balanced to result in profiles **1006** and **1008**. Profiles **1006** and **1008** remain proportional to each other but are also capacity balanced across subcarriers.

In an embodiment, as described above, capacity balancing of upstream bit loading profiles can be performed by the FCU. As described above, the FCU PHY has knowledge of the upstream bit loading profiles of CNUs that it serves. For example, the FCU can measure the upstream bit loading profile for a CNU, by measuring the SNR on each subcarrier from the CNU and calculating a symbol bit loading for each subcarrier based on the SNR measurement. In an embodiment, the FCU can compare the upstream bit loading profiles of CNUs that it serves and can decide to adjust one or more the upstream bit loading profiles to facilitate the sharing of upstream OFDMA frames by the CNUs. For example, the FCU (e.g., using a PHY controller, such as PHY controller **720**) can adjust the first upstream bit loading profile of a first CNU based on a comparison of the first upstream bit loading profile with a second upstream bit loading profile of a second CNU. The adjustment can be in order to render the first and second bit loading profiles proportional to one another across subcarriers in the OFDMA frame. Alternatively or additionally, the adjustment can be in order to capacity balance the first bit loading profile across subcarriers in the OFDMA frame.

FIG. **11** illustrates an example process **1100** according to an embodiment. Example process **1100** is provided for the purpose of illustration only and is not limiting of embodiments. Example process **1100** can be performed by a CNU, such as example CNU **300**, in order to map a MAC bit stream to an upstream scheduled multi-subcarrier frame. In an embodiment, the multi-subcarrier frame includes an OFDMA frame that includes a plurality of time consecutive OFDMA symbols.

As shown in FIG. **11**, process **1100** begins in step **1102**, which includes receiving a MAC bit stream. In an embodiment, the MAC bit stream is received from a MAC layer via a MAC-PHY interface, such as an XGMII interface. Subsequently, process **1100** proceeds to step **1104**, which includes determining a transmission time duration for the MAC bit stream. In an embodiment, step **1104** includes determining the transmission time duration for the MAC bit stream based on a bit size of the MAC bit stream and an upstream bit loading profile. The upstream bit loading profile determines for each available subcarrier of the multi-subcarrier frame the number of bits that can be carried by the subcarrier in one symbol of the frame.

Process **1100** then proceeds to step **1106**, which includes translating the transmission time duration into a frame number that identifies an upstream scheduled multi-subcarrier frame and a subcarrier group, which identifies a plurality of subcarriers of the multi-subcarrier frame. Then, in step **1108**, process **1100** includes determining whether or not all subcarriers of the subcarrier group have been filled with respective bits of the MAC bit stream. If the answer is yes, process **1100** proceeds to step **1110**, which includes transmitting the multi-subcarrier frame, symbol per symbol. Otherwise, process **1100** proceeds to step **1112**.

Step **1112** includes identifying the next subcarrier of the subcarrier to fill with bits from the MAC bit stream. The next subcarrier may or may correspond to the next subcarrier in frequency of the subcarrier group. For example, as described above in FIGS. **9** and **10**, the filling order of subcarriers can be shuffled according to embodiments to result in capacity balanced upstream bit loading profiles for CNUs.

Process **1100** then proceeds to step **1114**, which includes determining a symbol bit loading for the subcarrier, where the symbol bit loading indicates a number of bits that can be carried by the subcarrier in one symbol time. In an embodiment, the symbol bit loading is determined from the upstream bit loading profile. Then, in step **1116**, process **1100** includes determining, using the symbol bit loading, a total number of bits that can be carried by the subcarrier across the multiple time consecutive symbols of the multi-subcarrier frame. Process **1100** then proceeds to step **1118**, which includes mapping bits from the MAC bit stream to the subcarrier in accordance with the total number of bits determined in step **1116**. Process **1100** then returns to step **1108**.

Embodiments have been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

The foregoing description of the specific embodiments will so fully reveal the general nature of the disclosure that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present disclosure. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

The breadth and scope of embodiments of the present disclosure should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

**1**. An Ethernet Passive Optical Network over Coax (EPoC) physical layer (PHY) chip for use in a Coaxial Network Unit (CNU), comprising:

a PHY controller configured to receive a Medium Access Control (MAC) bit stream, determine a transmission time duration for the MAC bit stream, and translate the transmission time duration into a frame number and a subcarrier group, wherein the frame number identifies an upstream scheduled multi-subcarrier frame and the subcarrier group identifies a plurality of subcarriers of the multi-subcarrier frame.

**2**. The EPoC PHY chip of claim **1**, wherein the PHY controller is configured to receive the MAC bit stream from a MAC layer via a MAC-PHY interface.

**3**. The EPoC PHY chip of claim **2**, wherein the PHY controller is configured to determine the transmission time duration for the MAC bit stream based on a bit size of the MAC bit stream and an upstream bit loading profile.

**4**. The EPoC PHY chip of claim **3**, wherein the PHY controller is configured to determine the bit size of the MAC bit stream based on a start transmission time and an end transmission time of the MAC bit stream over the MAC-PHY interface.

**5**. The EPoC PITY chip of claim **4**, wherein the PHY controller is configured to translate the transmission time duration into the frame number and the subcarrier group based on the start transmission time of the MAC bit stream over the MAC-PHY interface.

**6**. The EPoC PHY chip of claim **1**, wherein the multi-subcarrier frame includes an Orthogonal Frequency Division Multiple Access (OFDMA) frame comprising a plurality of time consecutive OFDMA symbols.

**7**. The EPoC PHY chip of claim **1**, wherein the PHY controller is further configured to map the MAC bit stream to the subcarrier group based on an upstream bit loading profile.

**8**. The EPoC PHY chip of claim **7**, wherein the multi-subcarrier frame comprises multiple time consecutive symbols, and wherein the PHY controller is further configured to:

determine a symbol bit loading for a subcarrier of the subcarrier group from the upstream bit loading profile, wherein the symbol bit loading indicates a number of bits that can be carried by the subcarrier in one symbol time;

determine, using the symbol bit loading, a total number of bits that can be carried by the subcarrier across the multiple time consecutive symbols of the multi-subcarrier frame; and

map bits from the MAC bit stream to the subcarrier in accordance with the total number of bits.

9. The EPOC PHY chip of claim 1, wherein the PHY controller is further configured to:

transmit a signal on an upstream control channel according to a local frame start time;

receive a time offset on a downstream control channel; and

adjust the local frame start time using the time offset.

10. A method, comprising:

receiving a Medium Access Control (MAC) bit stream;

determining a transmission time duration for the MAC bit stream; and

translating the transmission time duration into a frame number and a subcarrier group, wherein the frame number identifies an upstream scheduled multi-subcarrier frame and the subcarrier group identifies a plurality of subcarriers of the multi-subcarrier frame.

11. The method of claim 10, wherein determining the transmission time duration for the MAC bit stream comprises determining the transmission time duration for the MAC bit stream based on a bit size of the MAC bit stream and an upstream bit loading profile.

12. The method of claim 10, wherein the multi-subcarrier frame includes an Orthogonal Frequency Division Multiple Access (OFDMA) frame comprising a plurality of time consecutive OFDMA symbols.

13. The method of claim 10, wherein the multi-subcarrier frame comprises multiple time consecutive symbols, and wherein the method further comprises:

determining a symbol bit loading for a subcarrier of the subcarrier group, wherein the symbol bit loading indicates a number of bits that can be carried by the subcarrier in one symbol time;

determining, using the symbol bit loading, a total number of bits that can be carried by the subcarrier across the multiple time consecutive symbols of the multi-subcarrier frame; and

mapping bits from the MAC bit stream to the subcarrier in accordance with the total number of bits.



14. The method of claim 10, further comprising:

transmitting a signal on an upstream control channel according to a local frame start time;

receiving a time offset on a downstream control channel; and

adjusting the local frame start time using the time offset.

15. An Ethernet Passive Optical Network over Coax (EPoC) physical layer (PHY) chip for use in a Coaxial Network Unit (CNU), comprising:

a Medium Access Control (MAC) layer configured to output a MAC bit stream over a MAC-PHY interface; and

a PHY controller configured to receive the MAC bit stream via the MAC-PHY interface, determine a transmission time duration for the MAC bit stream, and, based on a start transmission time of the MAC bit stream over the MAC-PHY interface, translate the transmission time duration into a frame number and a subcarrier group.

16. The EPoC PHY chip of claim 15, wherein the MAC layer is synchronized with a serving optical line terminal (OLT) MAC layer.

17. The EPoC PHY chip of claim 15, wherein the frame number identifies an upstream scheduled multi-subcarrier frame and the subcarrier group identifies a plurality of subcarriers of the upstream scheduled multi-subcarrier frame.

18. The EPoC PHY chip of claim 15, wherein the PHY controller is configured to determine the transmission time duration for the MAC bit stream based on a bit size of the MAC bit stream and an upstream bit loading profile.

19. The EPoC PHY chip of claim 17, wherein the upstream scheduled multi-subcarrier frame includes an Orthogonal Frequency Division Multiple Access (OFDMA) frame comprising a plurality of time consecutive OFDMA symbols.

20. The EPoC PHY chip of claim 15, wherein the PHY controller is further configured to map the MAC bit stream to the subcarrier group based on an upstream bit loading profile.

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UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION



PATENT NO. : 9,253,554 B2
APPLICATION NO. : 14/029180
DATED : February 2, 2016
INVENTOR(S) : Goswami et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

Column 14, Line 42. Please replace "PITY" with --PHY--.

Signed and Sealed this
Third Day of May, 2016

Michelle K. Lee

Michelle K. Lee
*Director of the United States Patent and Trademark Office*